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Nitrogen Uptake and Nitrogen Use Efficiencies of Improved and Hybrid Rice Varieties at Different Levels

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Abstract

Different nitrogen levels are recommended in rice production systems but the judicious use of nitrogenous fertilizer is of supreme importance for economically viable and environmentally safe production. A field experiment was conducted from June to November, 2017 in Agronomy Research Block of Agriculture and Forestry University (AFU), Rampur, Chitwan to study the effect of different N levels on nitrogen uptake and nitrogen use efficiencies of improved and hybrid rice varieties. The experiment was laid out in split plot design with four replications. Three varieties with two improved (Sabitri and Hardinath-1) and a hybrid (Arize Tej Gold) were used as main plot factor. Similarly, five N levels (0, 40, 80, 120 and 160 Kg N ha^{-1}) were used as sub-plot factor. Results revealed the highest grain, straw and total nitrogen uptake at 160 Kg N ha^{-1} which was significantly higher than any other doses and control. Partial Factor Productivity of Nitrogen (PFPN) of Arize Tej Gold hybrid was significantly higher (42.67 Kg grain Kg^{-1} N) than both Sabitri and Hardinath-1. In general, with significantly higher grain, straw and total nitrogen uptake, higher PFPN, hybrid rice showed more efficiency in nitrogen use so, the Arize Tej Hybrid can be considered as better varietal choice for increased profitability of the rice production system. Different indices of Nitrogen Use Efficiencies (NUE) showed decrease in efficiencies with the increasing levels of N application as found in the experiment.

Keywords: Nitrogen; Uptake; Efficiency; Improved and hybrid rice

Highlights

- Despite of the increase in the application of nitrogen worldwide, we are not being able to get the desired production of rice and various other crops yet.
- Nitrogen gets lost mostly through the volatilization, nitrate leaching, through runoff loss and denitrification resulting into higher costs of production and different environmental harms associated with soil microbes, water pollution etc.
- Nitrogen Use Efficiencies (NUE) decrease with the increasing levels of N application.
- Judicious use of nitrogenous fertilizer is of supreme importance for economically viable and environmentally safe production.

Introduction

Rice (*Oryza sativa* L.) is an annual, self-pollinated and semi-aquatic plant considered as one of the most important cereal crops of the world, grown in wide range of climatic zones. The global productivity of rice is 4.67 t ha^{-1} while in Asia is 4.82 t ha^{-1} [1]. In Nepal, it is cultivated on an area of 1.55 million ha; with production of 5.23 million tons and average yield of 3.36 t ha^{-1} respectively [2].

Nitrogen is the important determinant for the yield and its attributes. When the demand of nitrogen in plants is sub-optimal, the overall growth of plants is reduced, and it is the most yield-limiting nutrient in irrigated rice production around the world [3]. The quantity of grain yield is determined by the nitrogen uptake of plant and this varies among the varieties. Hybrid rice has physiological advantages over improved varieties in nitrogen uptake even under late planting, due to the genetic variation in internal efficiency of N [4]. Witt et al. stated that with uptake of 14.7 Kg Nitrogen, yield of rice was one ton [5]. Metwally et al. reported that application of nitrogen up to 250 Kg ha^{-1} also increased the nitrogen uptake in grains [6].

Nitrogen Use Efficiency (NUE) the portion of applied nitrogen that is absorbed and used by the plant. It can be considered as the amount of nitrogen taken and retained by the plant till harvest as compared to the prior total of nitrogen that was available for the crop [7]. Agronomic Efficiency (AEN) and Recovery Efficiency (REN), Partial Factor Productivity (PFPN) of nitrogen are the most frequently used indices for determining the NUE, however, AEN and REN are not suggested to compare crop yield of a treated plot with the control plot as control plot is devoid of all the management practices.

Despite of the increase in the application of nitrogen worldwide, we are not being able to get the desired production of rice and various other crops yet. With estimates averaging about 33% of fertilizer nitrogen recovery by the crop, the NUE for world cereal production is lower, which can be accounted for the irrational and unwise use of the nitrogenous fertilizer that has limited the actual crop production [7]. Nitrogen gets lost primarily through the volatilization, nitrate leaching, through runoff loss and denitrification resulting into higher costs of production with low nitrogen use efficiencies. Besides, it increases different environmental harms associated with soil microbes, water pollution and increased cost of production. In addition, research practitioners also perceive that more nitrogenous fertilizer and other inputs is demanded by the hybrids compared to improved varieties, and farmers adopt this with higher and imbalance use of inputs leading to low Nitrogen Use Efficiency (NUE).

In view of the above issues, the present study was undertaken to understand and determine the nitrogen uptake and nitrogen use efficiency of improved and hybrid rice varieties at different N levels under irrigated lowland condition in a humid sub-tropical irrigated ecosystem.

Materials and Methods

The experiment was conducted at the Agronomy research block of Agriculture and Forestry University (AFU) Rampur, Chitwan from July to November, 2017 in split plot design. Fifteen treatment combinations resulting from three varieties consisting of two improved viz. Sabitri and Hardinath-1 and one hybrid Arize Tej Gold (F1) as main plot treatments and five nitrogen levels viz. control, 40 Kg ha^{-1} 80 Kg ha^{-1}, 120 Kg ha^{-1} and 160 Kg ha^{-1} as sub plot treatments were selected which was replicated four times.

The physico-chemical properties of the soil of the experimental site were recorded and field was prepared with two deep plowing at a week interval followed by harrowing and planking. Field layout was performed maintain gross plot size of 4 m × 3 m (12 m^2), net plot size of net 5.4 m^2 and spacing of 20 cm × 20 cm. The plots were then irrigated and puddled manually before transplanting the 21 days seedlings at 2 per hill.

Each of the nitrogen levels were applied through urea containing 46% N in the nitrogen treatment plots i.e. 40 Kg ha^{-1}, 80 Kg ha^{-1}, 120 Kg ha^{-1} and 160 Kg ha^{-1} except for 0 Kg ha^{-1} in three split doses i.e. 50% as basal and first and second top dressing by 25% at tillering and 25% at panicle initiation stages respectively. Single super phosphate (16% P_2O_5) at the rate of 60 Kg P_2O_5 ha^{-1}, muriate of potash (60% K_2O) at the rate of 40 Kg ha^{-1} and zinc at the rate of 25 Kg ha^{-1} $ZnSO_4$ respectively were applied as basal dose. Two hands weeding at 25 DAT and 45 DAT were done in the experimental plots to reduce the weed infestation and competition between weeds and crops. Grains were winnowed for cleaning and weighed at their exact moisture content after manual harvesting and threshing with a paddle drum thresher. Similarly straw yield was recorded.

Oven-dried samples of grain and straw were tested for N content at soil lab of Agricultural Technology Center lab Pulchowk, Kathmandu. For estimating total nitrogen content of straw and grain, samples were digested with concentrated sulphuric acid and digestion mixture in micro Kjeldahl's assembly.

N uptake (grain and straw) was calculated by following formula:

N uptake (Kg ha^{-1})=Nitrogen content (%) × dry matter (Kg ha^{-1})/100

Different nitrogen use efficiencies were calculated with the following formulas:

Agronomic efficiency (AEN)=(GY-GY0)/FN

Recovery efficiency (REN)=(TN-TN0)/FN

Physiological efficiency (PEN)=(BY-BY0)/(TN-TN0)

Agro-Physiological efficiency (APEN)=(GY-GY0)/(TN-TN0)

Partial factor productivity (PFPN)=GY/FN

Where, GY is the grain yield of the treatment receiving applied N fertilizer; GY0 is the grain yield in a control treatment with no N fertilizer; FN is the amount of fertilizer N applied; TN is the total N uptake in aboveground biomass at maturity in a plot that received fertilizer N; TN0 is the total N uptake in aboveground biomass at maturity in a plot that received no fertilizer N; BY is the biological yield of the treatment receiving applied N fertilizer; BY0 is the biological yield in a control treatment with no N fertilizer.

The recorded data were subjected to Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) for mean separations. ANOVA was done to test the significant difference for each parameter at 0.05 significance level.

Results

Nitrogen uptake

The mean grain nitrogen uptake, straw nitrogen uptake and total nitrogen uptake was found to be 33.16 t ha^{-1}, 57.72 t ha^{-1} and 90.9 t ha^{-1} respectively which were significantly influenced by both the varietal differences and N levels used in the experiment (Table 1).

Nitrogen uptake (Kg ha^{-1})			
Treatments	**Grain nitrogen uptake**	**Straw nitrogen uptake**	**Total nitrogen uptake**
Variety			
Sabitri	29.98^b	57.49^b	87.5^b
Arize Tej Gold	44.79^a	72.09^a	116.9^a
Hardinath-1	24.71^b	43.57^c	68.3^c
SEm(±)	2.852	2.163	3.41
LSD (0.05)	9.868	7.484	11.79
CV,%	17.2	7.5	7.5
Nitrogen			
0 Kg N ha^{-1}	19.41^d	38.42^e	57.8^e
40 Kg N ha^{-1}	29.81^c	51.19^d	81.0^d
80 Kg N ha^{-1}	34.02^{bc}	57.69^c	91.7^c
120 Kg N ha^{-1}	38.10^b	66.32^b	104.4^b
160 Kg N ha^{-1}	44.44^a	74.96^a	119.4^a
SEm (±)	1.87	2.21	2.94
LSD (=0.05)	5.364	6.34	8.43
CV, %	19.5	13.3	11.2
Grand Mean	33.16	57.72	90.9
Note: Treatment means in columns followed by common letters are not significantly different from each other based on DMRT at 5% level of significance			

Table 1: Grain nitrogen uptake (Kg ha^{-1}), straw nitrogen uptake (Kg ha^{-1}) and total nitrogen uptake (Kg ha^{-1}) of improved and hybrid rice varieties as influenced by nitrogen levels at Agronomy Farm, AFU, Rampur in 2017.

Arize Tej Gold hybrid was significantly superior to both the improved varieties with GNU, SNU and TNU of 44.79 Kg ha^{-1}, 72.09

Kg ha^{-1} and 116.9 Kg ha^{-1} respectively. Among improved varieties, Sabitri was statistically superior to early variety Hardinath-1.

Significant differences on GNU were seen in case of N levels as well with increase in uptake in an increasing order with increment in the N levels up to 160 Kg ha^{-1}. Highest GNU of 44.44 Kg ha^{-1}, SNU of 74.96 Kg ha^{-1} and TNU of 119.4 Kg ha^{-1} was found in highest N level used i.e. 160 Kg N ha^{-1} followed by 120 Kg N ha^{-1}, 80 Kg N ha^{-1}, 40 Kg N ha^{-1} and control.

No significant interaction existed among varieties and N levels in grain nitrogen uptake.

But there was significant interaction effect among the varieties and N levels in straw nitrogen uptake (Figure 1). Highest straw uptake was obtained with application of 160 Kg N ha^{-1} in Arize Tej Gold which was significantly higher than other N levels and statistically at par with Sabitri in the same dose and Arize Tej Gold at 120 Kg N ha^{-1} application. Even with application of 80 Kg N ha^{-1}, Arize Tej Gold showed superior straw nitrogen uptake than other varieties. Lowest straw nitrogen uptake was found in Hardinath-1 at control N followed by Sabitri at control and 40 Kg N ha^{-1}.

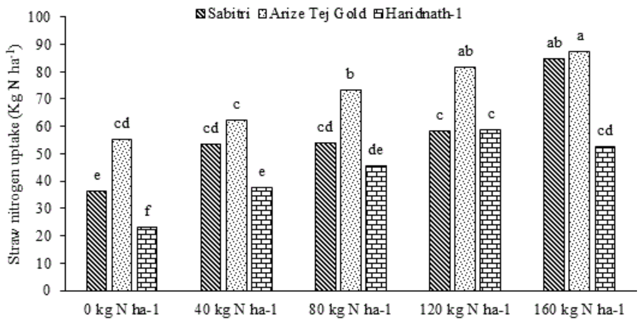

Figure 1: Interaction effect of varieties and N levels on straw nitrogen uptake at Agronomy Farm, AFU, Rampur, Chitwan, 2017.

Significant interaction of varieties and nitrogen levels were seen in total nitrogen uptake (Figure 2) similar to the straw nitrogen uptake. Arize Tej Gold hybrid had significantly higher total nitrogen uptake in 160 Kg N ha^{-1} and 120 Kg N ha^{-1} which was at par with Sabitri in 160 Kg N ha^{-1}. Poorest total nitrogen uptake was found in Hardinath-1 at control.

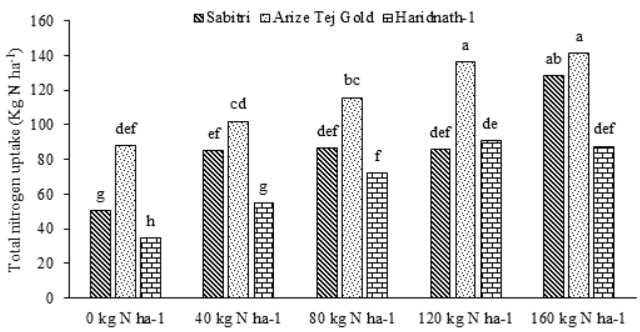

Figure 2: Interaction effect of varieties and N levels on total nitrogen uptake at Agronomy Farm, AFU, Rampur, Chitwan, 2017.

Nitrogen use efficiency

AEN, REN, PEN and APEN did not vary significantly among the varieties (Table 2). Highest AEN (13.63 Kg grain Kg^{-1} N) was observed in 40 Kg N ha^{-1} followed by 80 Kg N ha^{-1} (10.08 Kg grain Kg^{-1} N), 160 Kg N ha^{-1} (8.40 Kg grain Kg^{-1} N) and 120 Kg N ha^{-1} (8.39 Kg grain Kg^{-1} N) respectively but were not significantly different. Application of 40 Kg N ha^{-1} showed highest REN (0.579) which was significantly higher than all other doses in comparison followed by 80 Kg N ha^{-1} (0.424), 120 Kg N ha^{-1} (0.388) and 160 Kg N ha^{-1} (0.385) respectively which all were statistically similar.

PEN with the application of 40 Kg N ha^{-1} was highest (97.4 Kg grain Kg^{-1} N) and significantly greater than 80 Kg N ha^{-1} (79.9 Kg grain Kg^{-1} N) and 160 Kg N ha^{-1} (80.3 Kg grain Kg^{-1} N) respectively. Moreover, the interaction between varieties and N levels showed significant effects on PEN (Figure 3). PEN was significantly higher in the hybrid when 40 kg N ha^{-1} was used while decreased significantly with increasing N rates.

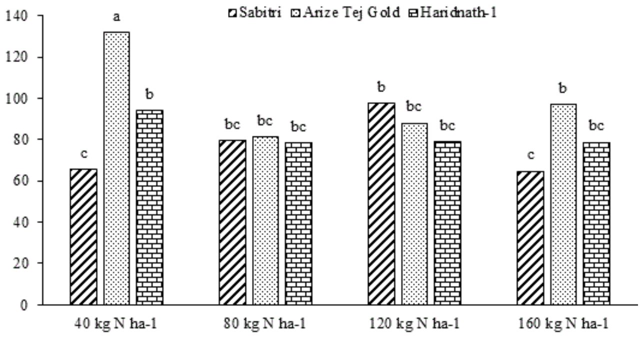

Figure 3: Interaction effect of varieties and N levels on physiological efficiency of nitrogen at Agronomy Farm, AFU, Rampur, Chitwan, 2017.

APEN was not found significant among the N levels as well whereas PFPN was found significantly affected by varieties as well as N levels (Table 2). Among the tested varieties, Arize Tej Gold hybrid (42.67 Kg grain Kg^{-1} N) had significantly greater PFPN than both Sabitri and Hardinath-1 varieties. Both the improved varieties were statistically at par. Furthermore, application of 40 Kg N ha^{-1} with PFPN of 50.71 Kg grain Kg^{-1} N was significantly higher than other doses of 80, 120 and 160 Kg N ha^{-1}. Even 80 Kg N ha^{-1} with PFPN of 28.62 Kg grain Kg^{-1} N was significantly higher to higher rates of N application (120 and 160 Kg N ha^{-1}). Application of 120 Kg N ha^{-1} and 160 Kg N ha^{-1} resulted in PFPN of 20.75 Kg grain Kg^{-1} N and 17.67 Kg grain Kg^{-1} N respectively which were statistically at par. Results have suggested PFPN to be decreasing with increasing N application rates upto 160 Kg N ha^{-1}.

Nitrogen use efficiency					
Treatments	**Agronomic efficiency**	**Recovery efficiency**	**Physiological efficiency**	**Agro physiological efficiency**	**Partial factor productivity**
	(AEN) Kg grain Kg^{-1} N	**(REN)**	**(PEN) Kg grain Kg^{-1} N**	**(APEN) Kg grain Kg^{-1} N**	**(PFPN) Kg grain Kg^{-1} N**
Varieties					
Sabitri	9.88	0.53	77	20.3	23.84^{b}

Arize Tej Gold	9.41	0.36	99.7	29.3	42.67ᵃ
Hardinath-1	11.09	0.44	82.8	27.8	21.80ᵇ
SEm(±)	1.54	0.07	8.93	4.22	2.04
LSD (0.05)	ns	ns	ns	ns	7.06
CV,%	30.3	31	20.6	32.7	13.9
Nitrogen levels					
0 Kg N ha^{-1}	-	-	-	-	-
40 Kg N ha^{-1}	13.63	0.58^{a}	97.40^{a}	30.1	50.71^{a}
80 Kg N ha^{-1}	10.08	0.42^{b}	79.90^{b}	28.2	28.62^{b}
120 Kg N ha^{-1}	8.39	0.39^{b}	88.40^{ab}	22.1	20.75^{c}
160 Kg N ha^{-1}	8.4	0.39^{b}	80.30^{b}	22.9	17.67^{c}
SEm(±)	1.448	0.0512	4.49	4.29	1.517
LSD (0.05)	ns	0.145	13.02	ns	4.4
CV,%	49.6	40	18	57.6	17.9
Grand Mean	10.13	0.44	86.5	25.8	29.44
Note: Treatment means in columns followed by common letters are not significantly different from each other based on DMRT at 5% level of significance					

Table 2: Nitrogen use efficiency of improved and hybrid rice varieties influenced by nitrogen levels at Agronomy Farm, AFU, Rampur in 2017.

Additionally, the interaction between varieties and N levels showed significant effects on PFPN (Figure 4). Interaction showed PFPN to be significantly higher at N control with Arize Tej Gold variety. Effects of interaction showed decreasing PFPN with increasing N levels with least efficiency in 160 kg N ha^{-1} and 120 kg N ha^{-1} for all the three varieties.

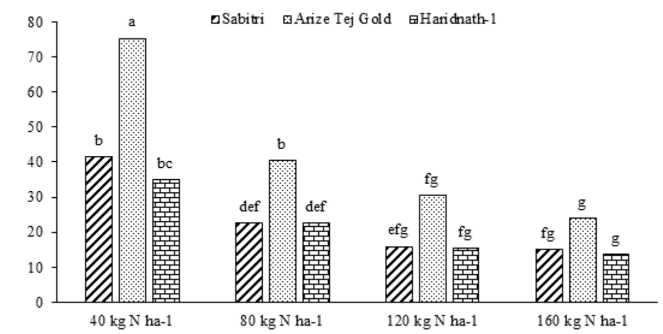

Figure 4: Interaction effect of varieties and N levels on partial factor productivity of nitrogen at Agronomy Farm, AFU, Rampur, Chitwan, 2017.

Discussion

Nitrogen uptake

The GNU, SNU and TNU of Arize Tej Gold hybrid was significantly higher than both the other varieties. Likewise, highest GNU, SNU and TNU was also found in highest N level used i.e. 160 Kg N ha^{-1} which was significantly higher than any other doses and control with an increasing uptake with increasing N levels.

Improvement in N uptake was also found with increased N levels by Sandhu et al. [8]. Dwivedi et al. reported the significant increase in nitrogen uptake of hybrid rice with the increase in N levels from 0 to 75, 150, and 225 Kg ha^{-1} N respectively and consequently [9]. N fertilizer significantly improved rice plant N uptake and also increased the grain yield. N uptake by grain and straw of hybrid rice was also positively influenced by N levels of 0, 60 and 120 and 180 Kg N ha^{-1} where N levels upto 180 Kg N ha^{-1} was statistically superior to other levels that enhanced uptake of NPK in grain and straw [10].

Nitrogen use efficiency

AEN gradually decreased with the increasing N upto 180 Kg N ha^{-1} whereas maximum at 60 Kg N ha^{-1} [10]. Meanwhile grain yield response to applied N follows law of diminishing returns; several researchers have reported of the declining trend in AEN with increasing N rate with highest values at lower N rates [11,12].

Significant differences in REN was found among the N levels but not with the differences in varieties used. However, REN in Sabitri (0.52) was the highest followed by Hardinath-1 (0.44) and Arize Tej Gold (0.36) respectively showing improved varieties to have higher capacity for nitrogen uptake per unit nitrogen applied. The science behind can be the higher N uptake from soil indigenous N, that was to some extent responsible for the dissimilarity in total N uptake between hybrid and inbred varieties which resulted in lower REN of hybrid than inbred varieties [13].

Application of 40 Kg N ha^{-1} showed highest REN (0.579) which was significantly higher than all other doses in comparison. Results of REN have indicated decrement in REN with increasing N dose upto 160 Kg N ha^{-1}. Like AEN, according to Singh et al., 2017, REN decreased gradually with increasing N rate with lowest values at 180 Kg ha^{-1} and the highest values at 60 Kg N ha^{-1} in two different years and based on pooled mean. The lower REN values at high N rates are best possible due to greater N losses through leaching, denitrification and ammonia volatilization. Similar results have been reported by Gupta et al. [14].

Significant differences in PEN were found in case of N levels. Application of 40 Kg N ha^{-1} showed highest PEN (97.4 Kg grain Kg^{-1} N). This is relevant with the trend with decrease in other indices of nitrogen use efficiencies with increasing N levels.

PFPN was found significantly affected by varieties as well as N levels. Among the tested varieties, PFPN was found significantly higher in Arize Tej Gold hybrid (42.67 Kg grain Kg^{-1} N) than both Sabitri and Hardinath-1 varieties. Hybrid rice had upto 19% higher PFPN than inbred cultivars as reported by Jiang et al. [13].

With increasing N application rates upto 160 Kg N ha^{-1}, PFPN was also found to be decreasing and significantly different. The results noticed that the crop fed with high nitrogen levels showed less efficient in recording PFPN. Crop with low nitrogen level (N 60 Kg ha^{-1}) recorded the maximum value of PFPN and the crop fed with higher nitrogen level (N180 Kg ha^{-1}) recorded the minimum value of PFPN respectively, during two different years [13]. These are in conformity with the findings of Sharma et al. [15].

Conclusion

From the results it can be concluded that, although uptake of nitrogen increases with increasing N levels applied, NUE of improved and hybrid rice varieties decreases with application of higher N levels. Among the varieties, with higher nitrogen uptake and partial factor productivity of N, Arize Tej Gold hybrid rice can be considered as a better varietal choice than other improved rice varieties under experimentation for increased efficiency of the system in irrigated lowland conditions.

Competing Interests

We declare that we have no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

Authors' Contributions

S. Marahatta and Y. Katuwal designed the model, the computational framework and analysed the data. Y. Katuwal carried out the experiment implementation, performed the calculations and wrote the manuscript with input from all authors. S. Marahatta, S. K. Sah and S. Dhakal were in charge of overall direction and planning.

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